THE VARIATION OF HYDROCARBON ABUNDANCES WITH LATITUDE AND SEASON IN SATURN'S STRATOSPHERE.

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Introduction: We have developed a realistic, time-variable, one-dimensional, seasonal model for stratospheric photochemistry on Saturn using the Caltech/JPL KINETICS code [1,2,3]. The model accounts for variations in ultraviolet flux due to orbital position, solar-cycle variations, and ring-shadowing effects. The results for two Saturnian years, starting at L_s = 0° in 1950 and running until the upcoming northern vernal equinox in 2009, are presented for numerous latitudes. The same two model years are run over and over again until the model convergences to make sure that high-altitude effects have had a chance to propagate down through the atmosphere.

We use the SOLAR2000 model [4,5], in combination with the spectra presented in [6], to predict the ultraviolet flux at any wavelength and any point in time during the simulation. Saturn's orbital position during the simulation was taken from the ephemeris calculator at http://ssd.jpl.nasa.gov/horizons.html [7]. The photochemical model is derived from "Model C" of [8] and uses a hydrocarbon reaction list that has been extensively updated from that presented in [3].

Results: The effects of ring shadowing on the solar insolation are illustrated in Figure 1, where the derivation of the ring-shadowing equations is described in [9]. Several interesting effects can be noted from the figures. First, ring-shadowing effects are pronounced at low latitudes, become progressively less important at middle latitudes, and are unimportant at high latitudes. Second, daily insolation values are relatively constant with latitude in the summer hemisphere near summer solstice because the increase in the length of daylight hours with increasing latitude counteracts the increasing solar zenith angle. Latitude variations are more pronounced at other times of the year. Third, the fact that Saturn's orbit is eccentric and that perihelion occurs near southern summer solstice causes an asymmetry in the daily mean insolation between the northern and southern hemispheres — higher daily mean insolation values are encountered during southern summer as opposed to northern summer. By the same token, daily mean insolation values at low latitudes in the southern hemisphere exhibit more seasonal variation than low latitudes in the northern hemisphere.

The latitudinal variation of the mixing ratios of C_2H_6 and C_2H_2 near southern summer solstice at different pressure levels is shown in Figure 2. At the highest altitude levels (lowest pressures), the atmosphere responds relatively quickly to insolation changes, and the hydrocarbon abundances have a latitude variation that resembles that of the solar insolation at L_s = 273° (see also Fig. 1). The variation with latitude at lower altitudes (higher pressures) is more complicated; long diffusion time scales and phase lags affect the latitudinal profiles. Because vertical diffusion time scales are long in Saturn's lower stratosphere, the mixing-ratio profiles of photochemically stable hydrocarbons at pressures greater than ~0.1 mbar in our model have a latitude variation that mimics the yearly average of the mean daily solar insolation, rather than mimicking the insolation variation from the current season.

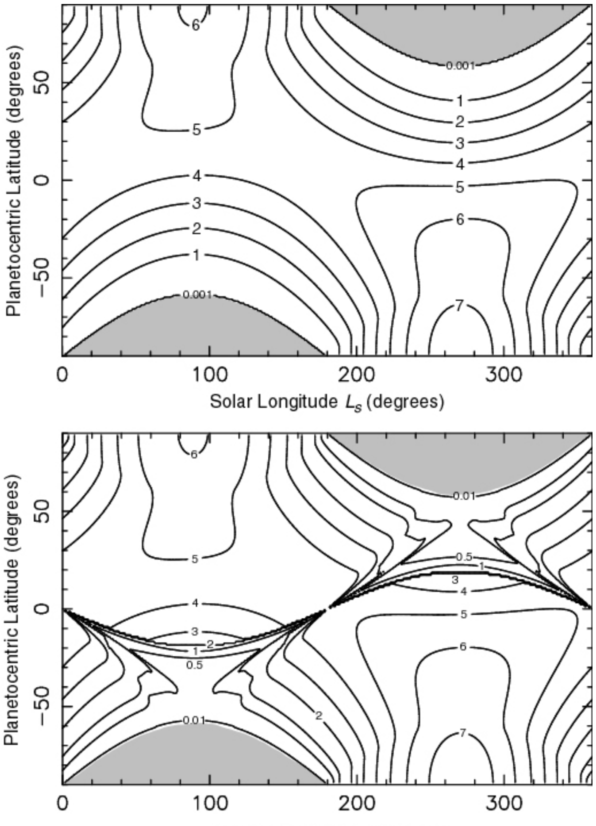

Figure 1. Daily mean solar insolation (W m^{-2}) incident on a unit horizontal surface at the top of Saturn's atmosphere as a function of latitude and season (L_s), assuming no ring shadowing (top panel) or with the inclusion of ring shadowing (bottom panel). The shaded regions indicate polar night. L_s = 0° at northern vernal equinox, 90° at northern summer solstice, 180° at northern autumnal equinox, etc.

In Fig. 2, we also compare the models profiles with results from high-resolution, ground-based, infrared observations using the TEXES grating spectrograph at the IRTF [10]. The shape of the observed C_2H_2 distribution is similar to that of the model. However, the observed latitude distribution of C_2H_6 does not compare well with the model. A quick examination of the relative photochemical lifetimes of the two species reveals a possible reason. The C_2H_2 photochemical lifetime is shorter than the estimated vertical and meridional transport time scales and is similar to or shorter than a Saturnian season. The C_2H_6 photochemical lifetime, on the other hand, is much greater than a Saturnian year and is longer than the estimated meridional and vertical transport time scales at the pressure levels at which the observations are sensitive. C_2H_6 is therefore likely to be sensitive to transport effects and should act as a good tracer for atmospheric motions.

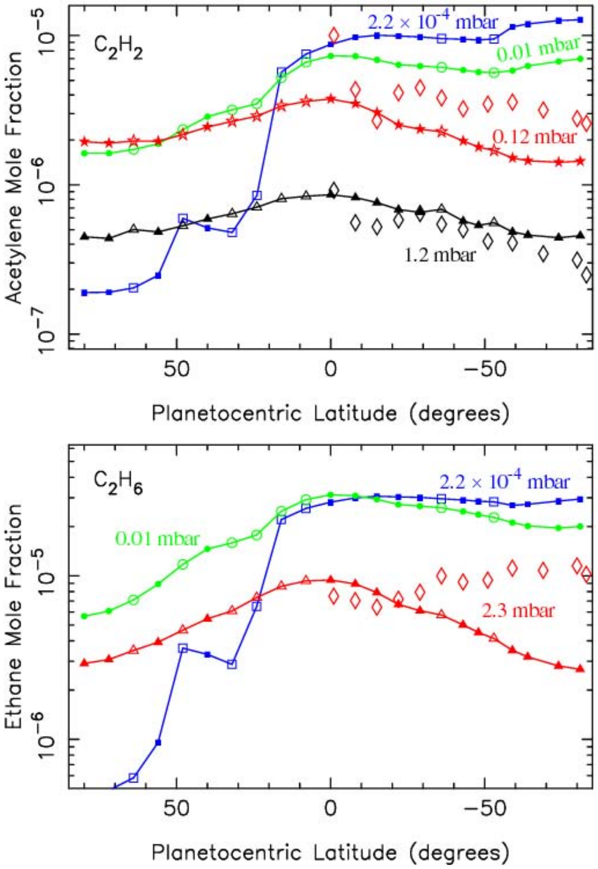

Figure 2. The latitudinal variation of the mixing ratios of C_2H_2 (top) and C_2H_6 (bottom) at L_s = 273° (near southern summer solstice) at different pressure levels, as labeled. The model profiles (solid lines) are compared with results from ground-based infrared observations (diamonds) [10] that were acquired at similar L_s. The open symbols in the model profiles represent models that have not yet converged.

Conclusions: Realistic 1-D photochemical models that accurately track the time variability of incident solar ultraviolet radiation should be able to reliably predict (and explain) the latitudinal/seasonal behavior of relatively short-lived hydrocarbons like CH_3, C_2H_2, C_2H_4, CH_3C_2H, and C_4H_2; however, more observations are needed to test this claim. Longer-lived hydrocarbons like C_2H_6 and C_3H_8 are more affected by atmospheric transport. Observations of the horizontal distribution of these long-lived species can help constrain stratospheric circulation patterns, and 2-D photochemical models will be needed to explain the observed latitudinal/seasonal behavior. Hydrocarbons located at pressures less than a few microbars will respond rapidly to changes in solar insolation; seasonal and latitudinal variations will be pronounced, and the ring shadow (and winter polar night) will strongly affect species abundances. In the middle and lower stratosphere, the latitudinal and seasonal distribution of hydrocarbons will be complicated and will depend on the relative magnitudes of the photochemical production and loss time scales, the vertical diffusion time scale, and the meridional transport time scale. Stable hydrocarbons residing at pressures greater than ~1 mbar will be much less affected by latitude and season and will have latitudinal distributions that resemble that of the yearly average mean daily solar insolation.

Cassini will map the hydrocarbon distributions on Saturn for the next several years, and these maps will provide a good test for our models, as well as good constraints for future 2-D models that include atmospheric transport. Ground-based infrared observations will continue to provide valuable information for seasons other than those encountered during the *Cassini* era and for altitudes that cannot be probed by the *Cassini* instruments.

References: [1] Allen, M. et al. (1981), *Astrophys. J. Suppl. Ser.*, 55, 465-506. [2] Yung, Y. L. et al. (1984), *J. Geophys. Res.*, *86*, 3617-3627. [3] Moses, J. I. et al. (2000), *Icarus, 143*, 244-298. [4] Tobiska, W. K. et al. (2000), *J. Atm. Solar Terr. Phys., 62*, 1233-1250. [5] Tobiska, W. K., and S. D. Bouwer (2004), *Adv. Space Res.*, COSPAR meeting. [6] Woods, T. N., and G. J. Rottman (2002), In *Atmospheres in the Solar System. Comparative Aeronomy*, (edited by M. Mendillo, A. Nagy, and J. H. Waite), 221-233. [7] Giorgini, J. D. et al. (1996), *BAAS*, 28, 1158. [8] Moses, J. I. et al. (2005), to be submitted to *J. Geophys. Res*. [9] Bézard, B. (1986), Ph. D. Thesis, Univ. Paris 7, France, pp. 229-237. [10] Greathouse, T. K. et al. (2005), submitted to *Icarus*. [11] Nixon, C. A., et al. (2005), submitted to or *Icarus*.

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